The Role of Visual Function in Animal and Human Evolution

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THE ROLE OF VISUAL FUNCTION IN ANIMAL AND HUMAN EVOLUTION.*

When scientific interest first appeared it concerned those things farthest removed from the observer and of the least vital importance to him. During thousands of years the intellect gradually approached the consideration of the human being himself. Astronomy was the first of the sciences; then man discovered his own world. The beginning of biology came nearer home than geology, and through numerous approaches and standstills man finally reached his own body. The bones of that body were his first care, then physiology was found; psychology is now emerging. It is natural that the law which expresses the order of the diverse kinds of discoveries should hold when applied to the stages of progress in each individual type. It follows that in zoology and physiology, the nearest and most important conditions which have brought about the exclusion of the unfit have been deferred for final findings and scrutiny, and we are now entering upon this last stage of accounting.

Hitherto the interaction of organism and environment has largely summarized the philosophy of biologic development, followed at once by the admission that the environment is the predominant factor, and that the individual organism has but little influence upon the outside circumstance. The truth seems rather to be that, when rightly estimated, the human organism, as a whole, has largely made its own environment, and that civilization is progressively taking almost entire charge of it.

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With this recreation of the environment by humanity will come the recognition of the hitherto-unseen truth that the most intimate and influential part of the environment is man's own body. Following this it will also be admitted that the individual variants of organs, such as imperfect senses, traumatisms, diseases, etc., not to be accounted for by heredity, are powerful factors in making misfits and unfits of such organisms and thus excluding them from the phylum.

Whether the controversy concerning the inheritance of acquired characteristics shall be settled in one or another way, the speediest and surest method will be by the study of the action of the inheritance of disease. And especially as to those diseases which depend upon ametropia. Here is an astonishing mass of evidence collated and placed in the hand. If it were used, the controversy would soon be illuminated. The people, rightly or wrongly, also believe that they "inherited" their headaches, sick headaches, and morbid nervous diseases. A very little careful testing would prove or disprove both the scientific and the popular faiths. Thus, again, as always, what is good science is good benevolence. Pathology would soon settle more scientific and social problems than normal physiology or morphology.

This gives warrant for criticism of that too common prejudice which excludes pathology from scientific consideration. It would rather seem that all other factors combined hardly equal in efficacy that of disease in excluding the unfit from genetic function. The morbidity and mortality rates, even among animals, and certainly in human life, markedly govern the evolution and characteristics of the phylogeny.

If so much is admitted, then the function of vision has been a strangely overlooked factor in the development of fit and unfit, and in shaping animalian and human trends and products. This is because vision is the most directional component, the *sine qua non*, indeed, of that part of the environment called the body: it intermediates between that body and the more external world; between man's hands and himself; between his mentality and his corporeality. The reason for the preponderant role of the eye in the development of unfitness lies in the difficulties encountered in its creation and present perfecting. It has been the severest task of the biologic process, and its imperfections are still a vast and growing source of the imperfections, characteristics, and failures of that process itself.

These difficulties may be roughly classified as those which relate to:

1. The embryology and optics of the eyeball.

2. The role of vision in the development of self-motility of the body.

3. The progress from divergence to parallelism of the optic axes, or from laterality to forward-looking.

4. The adaptations consequent upon the assumption of the vertical posture of the body.

5. The development of the shading mechanisms of the retina.

6. The struggle against astigmatism and other forms of ametropia, accommodational failure, cataract, ocular and systemic disease.

1. In view of the fact that the ether is the chief medium connecting organism and environment, the knowledge and utilization of the external world was possible only through the development of visual function. The fundamental difficulty in the construction of the eye was to devise a mechanism which should react instantaneously, accurately, and for a lifetime, to a stimulus hundreds of millions of millions slighter in kinetic energy than that, for instance, of sound waves. There is a keen suggestion of this difficulty shown by embryology. Within a few weeks after fertilization, the ovum, nearly synchronous with the differentiation of muscular tissue, shows the eyes in beginning formation. That it is so early, and that eye and muscle develop at the same time, is strikingly significant, for neither alone, certainly not the muscular system alone, would be either possible or of use. *Ubi motus ibi visus!* If "the ontogeny repeats the phylogeny," then the long stage of coincident embryonic evolu-

tion of the visual and muscular organs demonstrates an amazingly long period during which the difficulties and imperfections of either or of both were overcome. Those individuals and types in which these imperfections were the greatest must have been those excluded from the phylum because of unfitness. The undoubtedly greater difficulty of device in making the eyes renders it clear what delayed the perfecting of bodily mechanism, and why the unfit were preeminently those that were visually unfit.

A still more significant fact is that the brain comes out to see: cerebral substance is pushed outward to make the essential ocular structure—the retina. In no other instance is this embryonic process the same; and the reason seems clear that in no other is such a procedure necessary: the mechanism could not be devised, as in the other organs and senses, with the crude and refractory materials at the disposal of the organismal artificer. It was only with its own highly differentiated and complex cerebral substance that the complex and differentiated retina could be constructed and kept in life and repair—as the food of the babe is part of the mother's own tissues. The number of medullated nerve fibers of the human optic nerve is about 438,000, the number of retinal cone-cells at birth between 3,000,000 and 4,000,000. Noteworthy is the fact that the creation of the eye at birth is incomplete; the number of cones in the adult is double that of the babe. The number of retinal rods has been estimated as high as 130,000,000. Upon these hundred million rods and cones, as if upon so many bunched finger-tips of a blind man, is laid the warm picture, made by light, of the external scene, and the blind man sees, his crowded and extended fingers making, as it were, an eye.

The sensitive film of this living camera had to become a perfect mechanism of color-photography; had to be resensitized in an instant for a million pictures a day! All the adventitious peripheral structures—cornea, aqueous, crystalline lens, and vitreous—had also to be made and kept transparent without the usual red blood-corpuscles always necessary elsewhere. Such are a few of the difficulties encountered and overcome. Failure in any part inevitably threw out the individual, good in every other way, as unfitted to survive. If at the present time millions are thus excluded, what must have been the havoc in the animalian and savage past?

2. Adaptation to the environment and utilization of it by the organism was and remains impossible without the intermediate of self-motility. But this was likewise impossible without the prerequisite of vision to make the outside world known. Hence the synchronous and coincident development of the ocular and muscular systems. The accurate spacial and topographic representation of the objective world by the visual mechanism, and intimate, instant, and dominating guidance of all motor centers by the ocular picture, thus become primal necessities. There is scarcely an organ, surely no striated muscle, that is not directly or indirectly the servant of the

eye. From animalian fight, shelter-seeking, and food-hunting, to Civilization's latest cunning and devising there is an ever-increasing interplay of seeing and doing, until now vision seems to have vastly outrun execution. With every cerebral motor center awaiting, instigated by and obeying the guiding vision, how numberless the failures due to a hundred diseases and faults of mechanism! The present world of the sick, hurt, and prematurely dying are innumerable illustrations of the excluded unfit.

3. The optical axes, in the lower orders of the Mammalia, began with almost absolute divergence and proceeded toward parallelism through the progressing orders, until with the Simiæ and Man there is perfect parallelism.* The large range of the axes in the Marsupialia (from 75° to 30°) is suggestive, especially when that of the Carnivora is found to begin the overlapping at about 50° and reach to within 5° of the perfect parallelism of Simiæ and Man. The approach to parallelism may be looked upon as a kind of Ariadne clue through the maze of phylogenetic ascent. If we translate the approach toward parallelism, and its attainment by Simiæ and Man, in terms of the struggle for existence, we gain a new insight into the profound significance of the lateral and of the forward-looking kinds of vision. The greater the self-motility and the fighting ability, the greater the approach of the visual axes to parallelism, the large and small Felidæ being nearest that of the Simiæ and Man. The difficulty in attaining parallelism is of course due to

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*See Johnson, *The Mammalian Eye.*

the necessity of great modifications, not only in the bones of the face, but even in those of the skull, the transplacing of the orbits, etc. The more divergent the axes, the more gregarious, the more cowardly the animal. The common hare has 85° axes. What a vast and astonishing influence, therefore, has this factor had in the entire evolution of the fit, the exclusion of the unfit, in animal psychology, in morphology, indeed in every zoologic inquiry. It seems to have been entirely unsuspected.

4. In the same way the significance of the change in bodily posture from horizontality to verticality, effected in man, appears to have escaped proper recognition. It is man's most striking and differentiating characteristic, distinguishing him from the rest of the zoologic world. Has it been effected without a long and mighty struggle, without profound influence upon the victors, without exclusion of great numbers of the vanquished? Concealed by the slow process of ages we do not see the profound changes that occurred during the passage from horizontality to verticality of body. Think of placing a habitually horizontally-bodied animal on his hind legs only, his body erect, and one has a picture of what immense modifications of morphology, physiology, etc., must follow before the abused animal, if he lived a thousand years, would see and act with any approach to our "natural" seeing and acting. The Marsupialia and other relics of the halfway accomplishment of verticality exhibit most significant traces of the sorry ill successes. They may be described as the forty-five degree zoologic

failures. It would have been quite impossible to create visual organs equally well adapted to alternating horizontality and verticality. Hence the comparative failure and absence of numerous species even of the 45° types. The marsupial pouch is a necessary device to meet an exigency caused by the constriction of the pelvic outlet, which is due to the induced massiveness of the bony pelvis, and this a result of the body-weight resting upon these bones. The ovum soon after fertilization must be extruded at an early stage of gestation. In the kangaroo a special osseous support of the pouch is required—itself a hint of the failed struggle of the intermediating unfit. The primary necessity which drove the Simians (and the Marsupials, also, for that matter) toward verticality was tree-climbing, for food-getting partly, but more to escape from enemies. But *pari passu*, one should not forget, came the required perfection of ocular function with parallelism of the ocular axes.

Out of many great changes consequent upon the assumption by Simians and Man of the upright posture I select several illustrating the difficulties and dangers encountered in fixing and making permanent the habit.*

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*The mystery, seemingly so insoluble as to paralyze even the questioner, of the descent of the testes stands as the *bête noir* of medical science. I suggest that the amazingly strange makeshift of extruding the testes from the pelvic cavity is due to the collapsibility of the seminiferous tubules, epididymis, and especially of the vas deferens. Even the most habitual horizontality of posture of any animal is often and somewhat continuously changed for a partial uprightness. The weight of the superposed viscera would prevent the amazingly long journey of the spermatozoa through such thin collapsible tubules. In the subhuman Mammalia, therefore, the choked tubules would almost vitally endanger the propagation of the species and in the habitually upright Simian and Man it would

When we medical men do not know the etiology of a disease we take refuge in the solemnly-chanted words, *Diathesis*, *Neuropathic Diathesis*, *Neurasthenia*, *Hysteria*, etc. It may be said that in the human race spinal curvature is due to scoliotic diathesis! In a great American university, of about 1,200 Freshmen examined by experts, 80 percent had lateral spinal curvature. The proportion does not probably differ in any occidental country where school children are taught to write in the way advised by us. These 60,000,000 of United States folk have therefore not only the scoliotic "diathesis;" they have the scoliotic fact. The support of two-thirds of the body-weight by a single upright rouleau of ligatured bones, like that in the lumbar region, is an enormously expensive and hazardous proceeding. And yet accurate verticality might still be usually preserved if it were not for two ocular factors of mischief.* The morbid occidental writing-posture, due to ocular function and malfunction, together with some peculiar axes of astigmatism, are the active and sufficing causes of the great majority of cases of lateral spinal curvature. None may measure or calculate the part played by this astonishingly frequent scoliosis in the making of unfitness and in swelling the morbidity and mortality rates.

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stop it. Cryptorchidism is accompanied by impotence. Every physician knows that the majority of all hernias are secondary to abnormalisms of the pelvic wall consequent upon the extrusion of the testes. Does not this great present-day vital expense to the community point to exclusions of other millions of the unfit in past ages?

*Helpful is the often overlooked fact that we spend one-third of our lives in bed—in the old horizontal position.

Another cause and result (both peculiarly interwoven, as always in such proceedings) of permanent verticality of the body-trunk, consists in the freeing of the front feet and legs from the function of walking and running, and making them into the manipulating tools without which *Simia* could never have become *Homo*. Immediately and synchronously in development came the evolution of sign-language and of articulate language itself. The word *digit*, and the Roman numerals representing the fingers held up, are the living remains and evidence of the early stages of this evolution of the front foot, paw, and hand, as a tool, and also of language-formation.

According to the admitted localization of the cerebral centers controlling muscular acts, the center for articulate speech is located upon one side of the brain, adjacent to the center for writing. Articulate speech is a single, not dual act, and hence its center could not in one person be bilateral. For the same reason neither could the writing center be double. Consequently the writing center and the speech center are close neighbors, located in one cerebral hemisphere, the left in the right-handed, the right in the left-handed. The expert task of writing is carried out by the right hand, and because what is written is language (even now writing is correlated by the schoolboy with whisper and lip-motion), the contiguity of the centers in the *single* third frontal convolution is a necessity.

But there is now a new factor of great importance subtly introduced into the whole affair—that of a choice of one hand or of the other for special tasks. For certain delicate and expert ones the dextral hand was chosen in about 94 percent of men and women, in the other 6 percent the sinistral. In either case the less expert hand is the helper of, or the holder for the other. Among animals there is no trace of such differentiation into right and left, because, of course, both front paws are equally and almost solely used for walking, etc. In the four-footed, horizontally-bodied animal, to the divergent right eye, looking to the right side, was allotted the task of seeing the world to the right, and particularly of placing the right front foot. To the similarly divergent left eye was given the left side to watch out for, and the left foot to place.

There was in mammalian beginnings little forward-looking, because parallelism of the visual axes was ages ahead, and could not be complete until the front legs and paws could be relieved of locomotion, and, with the upright posture, put to manipulative uses. Such an animal blinded in one eye, was thus quickly excluded as unfit. Ophthalmic disease and traumatism, of course, was more and more frequent as we go back to more remote and primitive conditions and habits.

With the vertical posture came right-handedness and left-handedness, came parallelism of the optic axes, came downlooking, overlooking, outlooking, and forward-looking, and the immense and sudden leap from monkey to man! Necessarily there were, besides those heretofore bespoken, a hundred vitally important modifications, extensions, and perfectings of function and structure, which will long occupy the attention of future scientists. Of these we are here concerned with the ocular ones only; but what a vista is opened wherethrough we see the fittest to survive are often those that are only visually fit, and those excluded are they visually unadapted to the new conditions. Because, forget it not, the greatest perfection of visual function, from the day of assumed verticality, becomes the chief of all the agencies of progress. Ingenuity and intellect, speech, and writing, and printing, and language itself, could not follow without vision. The letters of the alphabet are conventionalized pictures, that is, ocular photographs; and memory, without which there can be no personality or individuality—memory and experience, are but a gallery of such photographs.

The latest complication and modification of visual function is a direct result of right-handedness; the eye-balls being placed 50 or 60 millimeters apart necessarily see two different pictures of an object. Therefore with delicate and dangerous tasks one eye must dominate. From the most primitive times the right foot or hand has been directed by the right eye, the left foot or hand by the left eye. With the evolution of right-handedness, upon the right eye has developed the duty of guiding in the more expert tasks. Hence the inevitable correlate of right-handedness is right-eyedness (dextrocularity), and of left-handedness it is left-eyedness. Indeed, I think that the precedent right-eyedness forces the choice of the right hand as that for the more expert task, writing, sighting a gun, etc.* The infant chooses the right hand with which to reach out and grasp things because it is right-eyed. All army regulations, uniform since Xenophon, cannot make the left-handed soldier into a right-eyed one. The question of right-handedness and right-eyedness has been a mighty one in all history; all military life, drill, and maneuver, chivalry, single combat, the rule of the road, etc., etc., are commanded by it. All mechanics, tools, etc., must consider it well. Early railway locomotive building worked for years aimlessly at the unknown problem of right-eyedness, until it was found out, none knew why, that the engineer must stand or sit on the right side of the boiler. Railway wrecks still occur because in three double-track roads passing is to the left.

So advanced is the fixation of right-eyedness that, in the right-handed, the right eye will retain its function of right-eyedness despite a far greater degree of amblyopia than in the left, caused by late arising disease or ametropia. The left eye is far more subject to disease than the right, and is the one usually thrown out of use by ametropia, heterophoria, etc. There are, I suspect, a million Americans whose right eye is the only useful one. Were it not that the nose hides from the right eye a considerable part of the world to the left side, it is probable that the trend toward a single or cyclopean eye would be greater than it is at present. In the light of the localization of the speech and writing center, and of the origin of right-handedness, the blunder of the Ambidexterity-monger is as maleficent as may be easily imagined. Every left-handed child taught by him to write (and that is all he tries or is able to do) with the dextral hand is thereby sadly and permanently injured.

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*I have had two left-handed patients who, compelled to shoot from the right shoulders, could take aim only when they depressed the right eye below the gun-level, and sighted with the left eye.

5. If one is able to fix the visual axis of one eye, without movement or winking, upon an illuminated object, it soon fades out and disappears. The sensitive film, the retina, can hold the image but a second or two. Constant change of stimulus, of the scene or image, variation of light and shade, etc., are necessary to retinal resensitization. The fact points to the fifteen mechanisms I have described which bring about this change of place, of stimulus, and of regenerating shadow.* Observation shows that the lower Mammalia have eyes inferior to man in visual power. The widely opened pupils and lids prove this fact even if other evidences were not manifes . All birds, nocturnal prowlers, etc., must see upward and widely about, so that the shading mechanisms of the human retina are necessarily absent. That the number of rods in the adult are twice those of the infant suggests far greater complexity and responsiveness of the visual function of man as compared with that even of the higher animals. It also prophesies further progress. But the

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*In birds the pecten, I suspect, unites in itself the most of these mechanisms, the large floating mass of waving vessels, with every movement of the bird's head, securing shadowing of one macula, while exposing that of the other eye. Birds, nocturnal prowlers, and those animals with habitually widely open lids have no astigmatism and thus have this compensation for their less sensitive retinas, etc.

shading mechanisms, in their totality, so necessary in man, are themselves demonstrations that in the ascent toward humanization and civilization the individuals superiorly equipped in these respects won in the struggle over those with less protected retinas.

Winking excepted, the chief of the human shadowing mechanisms is the position of the border of the upper lid at the upper edge of the pupil, followed by its instantaneous descent over the pupil in every act of winking. While hovering above the border, it is shading; when dropping over it, it is wholly blackening the retina. Its position is a consequence of the vertical position of the body and head, to shield the retina from the unused light above which would otherwise flood it with stimuli and thus drown photographic definition.

6. This inobviable necessity of the habitual placing the upper lid at the upper border of the cornea of vertical-bodied man brings with it a sad new evil, less pathogenic than would have been the excess of light, it is true, but still of enormous disastrous results to civilization. It is the chief cause of astigmatism. The cornea is warped by the pressure of the lid and one radius of its curvature is rendered greater than that at right angles to it. The retinal image of an astigmatic cornea does not therefore represent the true conditions and topography of the external world. The cerebrum is the organ of the inherited average of all past experience of approximately perfect visual images. The widely variant and morbid retinal stimulus passing through the 400,000 optic nerve fibers

to all parts of the cerebral switch-board, meets the infinitely complex but perfectly normal receiving and relaying mechanism. Resultant abnormalism of sensation, as to shape, color, accuracy of topography, etc., confuses the sensorium, and makes external action, based always upon vision, hazardous and ill-adapted for the act and for the individual. The individual must succumb, the race must persist. It is all a clear example of the truth that the body is really a part of the environment. Compounded with the other forms of ametropia as it usually is, we have the greatest of all environmental limitations to the progress of civilization. Almost every human eye has little or much astigmatism—there is not an optically or mathematically perfect pair of eyes in the world—and a small defect of shape may be more harmful and unfitting for the struggle for existence than the greater ones. The only miracle of ingenuity impossible for the ocular mechanic seems to be to make an eyeball true to within 1/200 or 1/300 of an inch. That fault of shape or measurement is constantly excluding millions from work in late social development and differentiation of function.

I beg you not to think or characterize this as the visionary imagining and exaggeration of specialism or of ill-balanced judgment. The reception of discoveries, medical or purely scientific, of the past, warns us that the greatest advances often spring from overlooked little things, and that prejudging is unsafe. Even as a military organization the German nation has far less validity than is necessary, because of myopia. The greatest ocular handicap after astigmatism is the hyperopic eyeball, well adapted for old-world life-tasks, but most ill-fitted for the inordinately demanded near-work of civilization. Astigmatism is the chief cause of myopia and of cataract. Astigmatism is unavoidable, but all its effects may be easily avoided. Accomodational failure, or presbyopia, is also inevitable, but its evils may also be circumvented. Handed down as a tradition of the past ages, an absurd premature senility and a long-drawn-out useless old age have become so customary that one may hardly recognize that both are the needless results of unnecessary eyestrain.

The catalogue of ills and the exclusions of the unfit, because of ocular malfunction, are by no means ended. The president of the *British Medical Association* officially emphasizes the testimony of hundreds of other careful scientific medical men that vast numbers ("millions," he says) suffering with incapacitating headache, produced by eyestrain, have been relieved by spectacles. The Governor of Massachusetts goes much further in his inaugural address, and a famous surgeon of New York City says he avoids a great number of abdominal operations by sending patients to oculists who cure them with glasses. The great majority of the diseases of the world's sick and prematurely dying began in functional disease which is of course simply abnormal physiology. The larger number of aberrant physiologic processes are directly or indirectly due to slight imperfections of measurements and shape of the eyeballs. Eventually they phase themselves into those mysteries of medicine called migraine, headache, sick headache, functional diseases of the digestive organs, lateral spinal curvature, kyphosis, nervous and mental diseases, such as insanity, much criminality, hysteria, neurasthenia, epilepsy, even suicide. There is an abundance and a growing mass of testimony that these diseases are very largely the consequences of morbid ocular function. Only the healthy are admitted to the future phylogeny: the diseased are unfit. It is easily possible to eradicate the diseases caused by eyestrain, and when the opportunity is realized, the number of medical men, colleges, and hospitals will be reduced by more than a half, the morbidity-rates and mortality-rates equally decreased, while the number of those endowing the future will be correspondingly increased.*

**Postscript.* In reference to the disadvantage of a high nasal bridge in man, it should be noted that oriental types have a higher wall between the eyes than the teutonic races who are now the chief carriers of an advancing civilization The statues of the classic Greek and Roman sculptors make the line joining the point of the nose and the forehead a straight one. The Jew of to-day illustrates the same inheritance, or indeed that from a more remote ancestry in which the bridge bowed forward or outward. With us, instead, there is a marked depression between the eyes which will probably increase, and thus will be avoided some of the limitations of the trend toward monocularity.